

*Hardware And Software For Performing Computations In A  
Short-code Spread-spectrum Communications System*

1. In a spread spectrum system of the type that processes a plurality of waveforms transmitted by respective users, the improvement comprising:

two registers associated with  $l^{th}$  and  $k^{th}$  users each for storing elements of a code sequence associated with one of the  $l^{th}$  and  $k^{th}$  users, an alignment of the code sequence loaded in one register being shifted relative to that of the other register by  $m$  elements,

two further registers, each for storing mask sequences associated with the code sequences of a respective one of the  $l^{th}$  and  $k^{th}$  users, such that a mask element is zero or non-zero if a corresponding element of the associated code sequence is zero or non-zero, respectively, an alignment of the mask sequence in one of the further registers being shifted relative to those in the other of the further registers by  $m$  elements,

a logic unit coupled to said registers for performing an arithmetical operation on said code sequences and mask sequences to generate, for  $m^{th}$  transmitted symbol,  $(l, k)$  element of a matrix that represents correlations among the code sequences associated with the respective users.

2. The system of claim 1, wherein the arithmetical operation comprises obtaining a sum of multipliers of non-zero aligned elements of the code sequences.
3. The system of claim 2, wherein the logic unit performs the arithmetical operation by, for any two aligned elements of the code sequences of the  $l^{th}$  and  $k^{th}$  user and the corresponding elements of the mask sequences, performing the following steps:
  - (i) performing an XOR operation between the code elements,
  - (ii) performing an AND operation between the mask elements,
  - (iii) performing an AND operation between results of the step (i) and step (ii) to generate a multiplier corresponding the aligned elements, and
  - (iv) summing the multipliers to generate the  $(l, k)$  element of the matrix.

4. The system of claim 3, wherein the logic unit comprises two AND gates each for performing one of said logic AND operations.
5. The system of claim 4, wherein the logic unit comprises an XOR gate coupled to said AND gates for performing said logic XOR operation.
6. The system of claim 5, further comprising storage for storing the computed matrix representing correlations among the code sequences associated with the users.
7. In a method of processing code spread spectrum waveforms transmitted by a plurality of users of a spread spectrum system, the improvement comprising:

generating a matrix for a shift of  $m$  chips indicative of correlations among code sequences associated with the users by performing the following steps:

- (i) for each user, loading elements of a code sequence associated with that user in a register, and loading a mask sequence associated with that sequence in another register such that a mask element is zero or non-zero if a corresponding element of the associated code sequence is zero or non-zero, respectively, and
- (ii) for any two users  $l$  and  $k$ , shifting an alignment of the code and mask sequences of the  $l$ th user relative to those of the  $k$ th user by  $m$  elements, and performing an arithmetical operation on the aligned elements to obtain  $(l, k)$  element of the matrix.

8. The method of claim 7, wherein the step of performing said arithmetical operation comprises obtaining a sum of multipliers of non-zero aligned elements of the code sequences.
9. The method of claim 8, wherein the step of obtaining the sum comprises performing following logic operations:

for any two aligned elements of the code sequences of the  $l$ th and  $k$ th user and the corresponding elements of the mask sequences performing the following steps:

- (i) performing an XOR operation between the code elements,
- (ii) performing an AND operation between the mask elements,

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- (iii) performing an AND operation between results of the step (i) and step (ii) to generate a multiplier corresponding the aligned elements, and
- (iv) summing the multipliers to generate the  $(l, k)$  element of the matrix.

10. The method of claim 9, further comprising the step of storing the matrix in persistent memory.
11. The method of claim 9, wherein the  $(l, k)$  matrix for a shift of  $m$  chips is defined in accord with the relation:

$$\Gamma_{lk}[m] \equiv \frac{1}{2N_l} \sum_{n=0}^{N-1} c_l^*[n] \cdot c_k[n-m]$$

wherein

$\Gamma_{lk}[m]$  represents correlation between  $l^{th}$  and  $k^{th}$  user codes corresponding to a shift of  $m$  chips,

$c_l^*[n]$  represents complex conjugate of the code sequence associated with the  $l^{th}$  user,

$c_k[n-m]$  represents the code sequence associated with  $k^{th}$  user,

$N$  represents the length of the code, and

$N_l$  represent the number of non-zero length of the code.

12. The method of claim 11, further comprising the step of computing a matrix (herein referred as C-matrix) that represents correlations among time lags and code sequences associated with the respective users in accord with the relation:

$$C_{lkqg}[m] = \sum_m g[mN_c + \tau] \cdot \Gamma_{lk}[m]$$

wherein

$g$  is a pulse shape vector,

$N_c$  is the number of samples per chip,

$\tau$  is a time lag, and

$\Gamma_{lk}[m]$  represents correlation between  $l^{th}$  and  $k^{th}$  user codes corresponding to a shift of  $m$  chips.

13. The method of claim 12, further comprising the step of computing a matrix (herein referred to as  $r$  matrix) representing cross-correlations among the waveforms transmitted by the users as a function of the  $C$  matrix in accord with the relation:

$$r_{lk}[m] = \sum_{q=1}^L \sum_{q'=1}^L \text{Re} \left\{ \hat{a}_{lq}^* a_{kq'} \cdot C_{lkqq'}[m] \right\} = \text{Re} \left\{ a_l^H \cdot C_{lk}[m] \cdot a_k \right\}$$

wherein

$\hat{a}_{lq}^*$  is an estimate of  $a_{lq}^*$  which is the complex conjugate of one multipath amplitude component of the  $l^{th}$  user,

$a_{kq'}$  is one multipath amplitude component associated with the  $k^{th}$  user, and

$C$  denotes the aforesaid  $C$  matrix.

14. The method of claim 13, further comprising the step of generating detection statistics corresponding to symbols transmitted by the users and encoded in the waveforms as a function of said cross-correlation matrix in accord with the relation:

$$y_l[m] = r_{ll}[0]b_l[m] + \sum_{k=1}^{K_y} r_{lk}[-1]b_k[m+1] + \sum_{k=1}^{K_y} [r_{lk}[0] - r_{ll}[0]\delta_{lk}]b_k[m] + \sum_{k=1}^{K_y} r_{lk}[1]b_k[m-1] + \eta_l[m]$$

wherein

$y_l[m]$  represents detection statistic for the  $m^{th}$  symbol transmitted by the  $l^{th}$  user,

$r_{ll}[0]b_l[m]$  represents a signal of interest, and

remaining terms of the relation represent Multiple Access Interference (MAI) and noise.

15. The method of claim 14, further comprising the step of estimating the transmitted symbols as a function of the detection statistics in accord with the relation:

$$\hat{b}_l[m] = \text{sign} \left\{ y_l[m] - \sum_{k=1}^{K_y} r_{lk}[-1]\hat{b}_k[m+1] - \sum_{k=1}^{K_y} [r_{lk}[0] - r_{ll}[0]\delta_{lk}]\hat{b}_k[m] - \sum_{k=1}^{K_y} r_{lk}[1]\hat{b}_k[m-1] \right\}$$

wherein

$\hat{b}_l[m]$  represents an estimate of the  $m^{th}$  symbol transmitted by the  $l^{th}$  user.

16. In a spread spectrum system of the type that processes a plurality of waveforms transmitted by respective users, the improvement comprising:

a first logic module for computing a matrix indicative of correlations among codes associated with the users, and

a second logic module in communication with said first logic module for computing a matrix indicative of cross correlations among the waveforms transmitted by the users as a function of the matrix representing correlations among the code sequences,

wherein the first logic module generates an  $(l, k)$  element of the matrix representing correlations among the waveforms transmitted by  $l^{th}$  and  $k^{th}$  users by performing the following operations:

- (i) for each user, loading elements of a code sequence associated with that user in a register, and loading a mask sequence associated with that sequence in another register such that a mask element is zero or non-zero if a corresponding element of the associated code sequence is zero or non-zero, respectively, and
- (ii) shifting an alignment of the code and mask sequences of the  $l^{th}$  user relative to those of the  $k^{th}$  user by  $m$  elements, and performing an arithmetical operation on the aligned elements to obtain  $(l, k)$  element of the matrix.

17. The system of claim 16, wherein the second logic module computes the cross-correlation matrix by computing a matrix component (herein referred to as C matrix) representing correlations among time lags and code sequences associated with the waveforms transmitted by the users in accord with the relation:

$$C_{lkq}[m] = \sum_m g[mN_c + \tau] \cdot \Gamma_{lk}[m]$$

wherein

$g$  is a pulse shape vector,

$N_c$  is the number of samples per chip,

$\tau$  is a time lag, and

$\Gamma_{lk}[m]$  represents correlation between  $l^{th}$  and  $k^{th}$  user codes corresponding to a shift of  $m$  chips.

18. The system of claim 17, wherein the second module computes the cross-correlation matrix as a function of the C matrix in accord with the relation:

$$r_{lk}[m] = \sum_{q=1}^L \sum_{q'=1}^L \text{Re} \left\{ \hat{a}_{lq}^* a_{kq'} \cdot C_{lkqq'}[m] \right\} = \text{Re} \left\{ a_l^H \cdot C_{lk}[m] \cdot a_k \right\}$$

wherein

$\hat{a}_{lq}^*$  is an estimate of  $a_{lq}^*$  which is the complex conjugate of one multipath amplitude component of the  $l^{th}$  user,

$a_{kq'}$  is one multipath amplitude component associated with the  $k^{th}$  user, and

$C$  denotes the aforesaid C matrix.

19. The system of claim 18, further comprising a third logic module in communication with said second logic module for computing detection statistics corresponding to symbols transmitted by the users.
20. The system of claim 19, wherein the third logic module computes estimates of the symbols transmitted by the users as a function of the detection statistics.